The Assessment of Musculoskeletal Injury Risks Among Steel Manufacturing Workers

Hazards are ever-present in the steel plant environment, and a heightened awareness and emphasis on safety is a necessary priority for our industry. This monthly column, coordinated by members of the AIST Safety & Health Technology Committee, focuses on procedures and practices to promote a safe working environment for everyone.

Authors

Xiaopeng Ning
assistant professor, Industrial and Management Systems Engineering, West Virginia University, Morgantown, W.Va., USA
xiaopeng.ning@mail.wvu.edu

Daniel E. Della-Giustina
professor, Industrial and Management Systems Engineering, West Virginia University, Morgantown, W.Va., USA
della-giustina@mail.wvu.edu

Boyi Hu
graduate research assistant, Industrial and Management Systems Engineering, West Virginia University, Morgantown, W.Va., USA
bohu@mix.wvu.edu

Contact

Comments are welcome. If you have questions about this topic or other safety issues, please contact safetyfirst@aist.org. Please include your full name, company name, mailing address and email in all correspondence.

Don B. Daily Memorial Fund

To Promote Steel Industry Safety and Health

This article is the third in a series of Safety First articles featuring the reports from the recipients of the 2013 Don B. Daily Memorial Fund. The first and second articles in the series were published in the August 2014 and September 2014 issues of *Iron & Steel Technology,* respectively. For a complete list of Don B. Daily Memorial Fund grant recipients, visit AIST.org.

Work tasks involved in steel manufacturing often require strength, endurance and precision, and can expose workers to a number of recognized musculoskeletal injury risks. Previously, a high prevalence of musculoskeletal disorders (MSDs), including lower back pain (LBP), neck pain, shoulder pain, hand/wrist dysfunctions, etc., was reported among workers in the steelmaking industry around the world (Daniel et al., 1980; Masset and Malchaire, 1994; Habibi et al., 2008; Aghilinejad et al., 2012). However, the risk factors and high-risk jobs/tasks that could cause MSDs among steelworkers have not been investigated. Without such knowledge, the design of effective ergonomic intervention becomes impossible and workers in steel mills may continue to suffer from MSDs.

To assess MSD risks on-site, a number of observational tools have been developed. One of the earliest observation tools is the Ovako Working Posture Analyzing System (OWAS), which was first introduced by a steel company from Finland in the 1970s (Karhu et al., 1977). In the 1980s and 1990s, the National Institute for Occupational Safety and Health (NIOSH) published its lifting equation to help ergonomists estimate the risks of back injuries caused by repetitive weight-lifting tasks (Waters et al., 1993). More recently, a whole-body postural analysis tool called Rapid Entire Body Assessment (REBA) was developed to analyze working postures of workers employed in the health care and service industries (Hignett and McAtamney, 2000). When using observational ergonomic assessment tools, a minimal amount of direct measurements is required; therefore, interruptions of workers' task performance can be minimized. During the on-site investigation, an experienced observer (often an ergonomist) will follow the motions that workers perform, record the types of exertion used and estimate the range of motions. This data will then be entered into the observational tools to generate index numbers which generally indicate the level of MSD risks. Such investigation is also cost-effective because of the simple instrumentation it requires.

However, field observation cannot provide the necessary quantitative data needed for the in-depth MSD risk factors assessment. Therefore, direct measurements are often performed in a laboratory environment to further investigate the hazardous tasks or risk factors identified by field observation. Commonly used direct measurement tools include electromyography (EMG), goniometry, optical sensing and electromagnetic sensing, etc. These instruments are often used to record the instantaneous muscle activity and body kinematics data.

The objective of this study was to identify the high-risk jobs/tasks workers perform in the steelmaking industry that may cause musculoskeletal injuries. To achieve this goal, both field observation and laboratory simulations (i.e., direct measurement) were used.

Methods

Field Observation — Similar to the ergonomic investigations conducted in other industries (Ning and Mirka, 2010; Mirka et al., 2011), a field study was first conducted in a steel manufacturing plant to identify work-related MSD risk factors in the steel manufacturing industry. During the site visit, injury records were analyzed, and potential hazardous tasks were selected and observed. After the visit, tasks that demonstrated a potentially high risk of MSD injuries were further simulated and analyzed under laboratory conditions. This paper focuses mainly on the results of the laboratory simulation study.

Subjects — Eight male participants were recruited from the West Virginia University student population. All subjects were free from any musculoskeletal disorder during the 18 months prior. The experiment procedure was approved by the West Virginia University Institutional Review Board. Written, informed consent was obtained from all subjects prior to the data collection.

Instrumentation and Apparatus — Data regarding muscular activities were collected from the left arm brachioradialis (LB), right arm brachioradialis (RB), left trapezius (LT), right trapezius (RT), left arm deltoid (LD), right arm deltoid (RD), left erector spinae (LES) and right erector spinae (RES) using bipolar surface electromyography (EMG) electrodes with a sampling frequency of 1,024 Hz. A D-handle was attached to a 6 degrees of freedom force/torque sensor to record the magnitude and direction of hand force exertions. Real-time graphical force output feedback was displayed on an LCD screen using the MyoResearch XP analysis software.

Protocol — When data collection started, the subjects first performed a series of maximum voluntary contraction (MVC) trials to collect maximum EMG activity from all measured muscles. The EMG data collected from MVC trials were later used for normalization. When the MVC trials were finished, the subjects were asked to perform two simulated tasks that workers perform in a steel manufacturing plant:

Metal Cutting: The metal-cutting task was designed to simulate the steel sheet-cutting task that workers perform at the coil inspection site. To perform this task, workers need to maintain an awkward trunk posture and exert a pushing force on a handheld metal-cutting saw to cut down the steel samples (Figure 1a). It was suspected that, during the performance of this task, workers may experience high muscle activation levels from arm, shoulder and lower back muscles. During the laboratory simulation of this task, subjects were asked to adopt a staggered foot posture, lean forward ~20° and push the D-handle forward using the right hand as the main pushing hand (Figure 1b). Subjects were required to exert 30N or 60N of force (simulating the force requirement of different hand tools) constantly for 6 seconds with the assistance of real-time visual feedback. Each subject performed six trials of metal-cutting tasks (three repetitions at each force level) in a completely randomized order. One minute of rest was provided between trials.

Tool Handling: During the project team's visit to the steel manufacturing plant, a number of maintenance workers reported that the grease on their hand tools significantly increases the difficulty of handling the tools and makes machine maintenance tasks more tiring (Figure 2a). An experiment was designed to quantify the effect of grease on the tool handles on trunk and upper extremity muscle activities. In this task,

Figure 1

(a) (b)

Actual (a) and lab-simulated (b) metal-cutting tasks.

subjects were asked to hold the D-handle firmly and exert 30N of force along three different commonly performed hand force exertion directions (forward, upward and leftward) with or without grease added to the handle (Figure 2b). Subjects performed a total of 18 trials (three repetitions for each condition) in a randomized order. One minute of rest was provided between trials.

Data Processing and Statistical Analysis — The raw EMG data were filtered with a high-pass frequency of 10 Hz, a low-pass frequency of 500 Hz, and a notch filter of 60 Hz and its aliases. The data were then full-wave rectified, and a half-second moving window was used to further smooth the profile. Next, EMG data were normalized with regard to the MVC EMG of each corresponding muscle. The students' t-test was used to analyze muscle activity differences between different conditions. The criteria p-value was 0.05 for all statistical analysis.

Results and Discussion

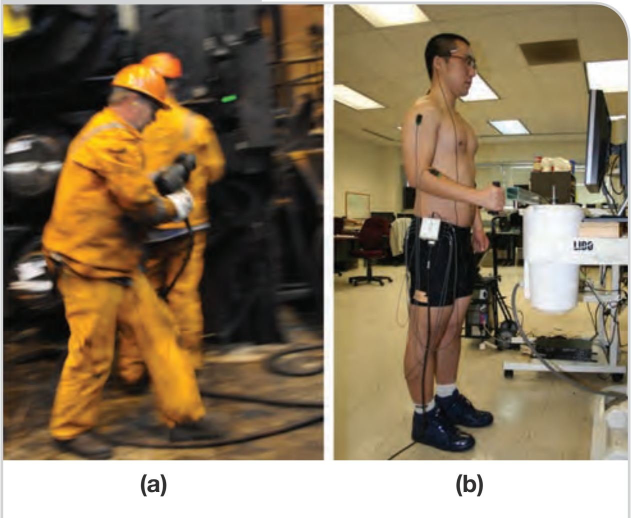
Metal Cutting — For the metal-cutting task, the results of the statistical analyses showed that the EMG activities on both sides of the erector spinae, trapezius, deltoid muscles and the right side brachioradialis were significantly increased with the increase of pushing force. Only the left brachioradialis muscle was not statistically significantly affected despite its average EMG activity increasing with the increase of pushing force. Among all eight muscles, the right brachioradialis had the largest increment (from 6.0% to 13.3%, p-value <0.001) (Figure 3).

The results demonstrated that metal-cutting tasks involve the use of not only arm and shoulder muscles, but also neck and lower back muscles. The increase of hand force output significantly elevated the muscle activation levels among almost all these muscles. Considering the sustained hand force exertion required by this task, significant risk of musculoskeletal injuries can be posed to workers' hands and wrists, shoulder joints, necks and lower back regions, especially when performing this task repetitively. According to these results, it is suggested that an effective hand tool (i.e., metal-cutting hand saw) that requires a smaller amount of hand force exertion should be adopted. In addition, to avoid cumulative MSD injuries, workers are advised to take ample rests between cutting tasks in order to reduce the negative impact of muscle fatigue caused by prolonged force exertion.

Tool Handling — For the tool-handling task, the results showed that adding grease to the handle significantly increased the EMG activities of the right and left trapezius, right brachioradialis, right deltoid and left erector spinae muscles when exerting hand force in an upward direction. The largest increment of muscle activity was observed on the right brachioradialis, which had a significant increase from 23.8% to 41.7% of MVC (p-value <0.001) (Figure 4). When performing leftward and forward (pushing) hand force exertions, although some elevated muscle activities were observed, these changes were not statistically significant (Figures 5 and 6).

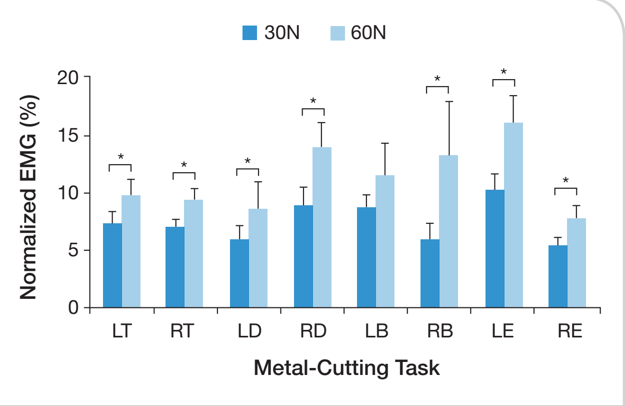
The results generally support the claims of maintenance workers that the grease on tool handles increases the difficulty of task performance. Interestingly, the

Figure 2



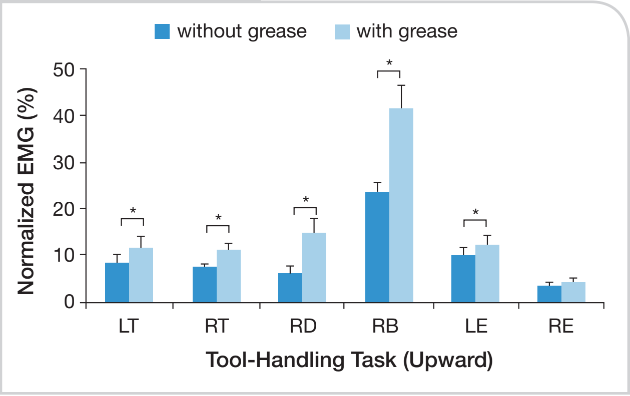
Actual (a) and lab-simulated (b) tool-handling tasks.

Figure 3



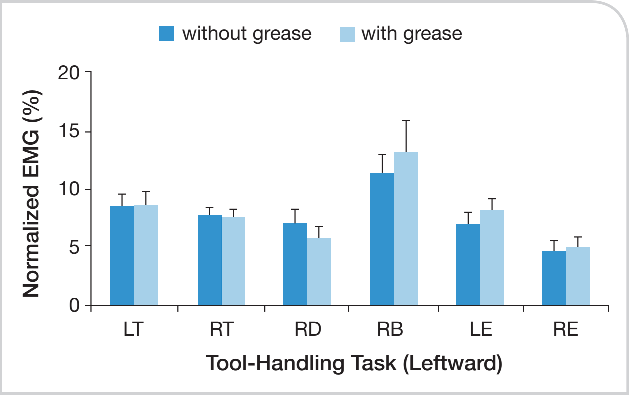
Normalized EMG activities of muscles during the performance of a metal-cutting task with different force exertion levels; asterisk indicates muscle activities that are significantly different from each other.

Figure 4



Normalized EMG activities of muscles during the performance of a tool-handling task with upward force exertion; asterisk indicates muscle activities that are significantly different from each other.

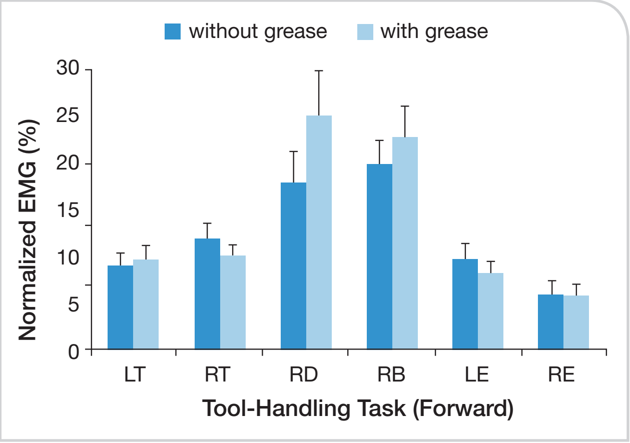
Figure 5



Normalized EMG activities of muscles during the performance of tool-handling task with leftward force exertion.

increases in muscle activities were significant only when exerting upward lifting forces, but not when exerting forward and leftward pushing forces. From Figure 4, it can be observed that when exerting force in an upward direction, grease on the handle increased the average muscle activation levels among the arm and shoulder muscles that are associated with MSDs among the hand and wrist complex and shoulder joints. Further, both sides of the neck muscles and the contralateral side (opposite to the side of force exerting hand) of the lower back muscle also demonstrated elevated muscle activities. It was suspected that with the influence of grease, neck and lower back muscles are activated to increase trunk stability and improve the control of the hand tool. Such increases of muscle activities could tie into the high rates of neck and lower back disorders reported previously among steel manufacturing workers (Aghilinejad et al., 2012). The results of this study suggested that, in order to improve maintenance workers' working conditions and reduce their MSD risks, it is critical to remove or reduce grease buildup on their hand tools, cables and machine surfaces.

Figure 6



Normalized EMG activities of muscles during the performance of tool-handling task with forward force exertion.

Conclusions

Results of this study showed that in a steel manufacturing plant, when performing the metal-cutting task, improper selection of cutting tools may increase the required hand force and consequently elevate upper extremity and lower back injury risks. In addition, the current study confirmed that the buildup of grease on tool handles increases the risks of MSDs among neck, lower back, and hand and arm regions during task performance, especially when exerting hand force in an upward direction. The current study demonstrated a quantitative approach to assess MSD risks involved in specific tasks performed by steel manufacturing workers. To gain a full understanding of the health risks associated with steel manufacturing jobs, more comprehensive investigation that adopts similar approaches should be conducted in the future.

References

1. Aghilinejad, M.; Choobineh, A.R.; Sadeghi, Z.; Nouri, M.K.; and Bahrami Ahmadi, A., "Prevalence of Musculoskeletal Disorders Among Iranian Steel Workers," *Iranian Red Crescent Medical Journal,* Vol. 14, No. 4, 2012, pp. 198–203.

2. Daniel, J.W.; Fairbank, J.C.T.; Vale, P.T.; and O'Brien, J.P., "Low Back Pain in the Steel Industry: A Clinical, Economic and Occupational Analysis at a North Wales Integrated Steel Works of the British Steel Corporation," *The Journal of the Society of Occupational Medicine,* Vol. 30, No. 2, 1980, pp. 49–56.
3. Habibi, E.; Fereidan, M.; Molla Aghababai, A.; and Pourabdian, S., "Prevalence of Musculoskeletal Disorders and Associated Lost Work Days in Steelmaking Industry," *Iranian Journal of Public Health,* Vol. 37, No. 1, 2008, pp. 83–91.
4. Hignett, S., and McAtamney, L., "Rapid Entire Body Assessment (REBA)," *Applied Ergonomics,* Vol. 31, No. 2, 2000, pp. 201–205.
5. Karhu, O.; Kansi, P.; and Kuorinka, I., "Correcting Working Postures in Industry: A Practical Method for Analysis," *Applied Ergonomics,* Vol. 8, No. 4, pp. 199–201.
6. Masset, D., and Malchaire, J., "Low Back Pain: Epidemiologic Aspects and Work-Related Factors in the Steel Industry," *Spine,* Vol. 19, No. 2, 1994, pp. 143–146.
7. Mirka, G.A.; Ning, X.; Jin, S.; Haddad, O.; and Kucera, K.L., "Ergonomic Interventions for Commercial Crab Fishermen," *International Journal of Industrial Ergonomics,* Vol. 41, No. 5, 2011, pp. 481–487.
8. Ning, X., and Mirka, G.A., "The Effect of Sinusoidal Rolling Ground Motion on Lifting Biomechanics," *Applied Ergonomics,* Vol. 42, No. 1, 2010, pp. 131–137.
9. Waters, T.; Putz-Anderson, V.; Garg, A.; and Fine, L., "Revised NIOSH Equation for the Design and Evaluation of Manual Lifting Tasks," *Ergonomics,* Vol. 36, No. 7, 1993, pp. 749–776.

✦